Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* (Anura: Hylidae)

Graham H. Pyke[1] and Arthur W. White[2]
[1]*Australian Museum*, 6 College Street, Sydney, New South Wales 2000.
[2]Biosphere Environmental Consultants, 69 Bestic Road, Rockdale, New South Wales 2216.

ABSTRACT

We examined the habitat features of sites where the Green and Golden Bell Frog is known to have been present, differentiating between those sites where breeding is known to have occurred and those where breeding has not been recorded. We found that, for a site to support a breeding population of the species, it should contain water bodies which are still, shallow, ephemeral, unpolluted, unshaded and free of *Gambusia* and other predatory fish. It should have a grassy area nearby and other nearby vegetation should be no higher than woodland. The substrate of the ponds should be sand or rock, aquatic plants should be present and there should be a range of possible diurnal shelter sites, including vegetation and rocks.

INTRODUCTION

The Green and Golden Bell Frog *Litoria aurea* is presently listed on Schedule 12 of the New South Wales *National Parks and Wildlife Act* 1974 as an endangered fauna species in New South Wales. It has gone from being a common frog in New South Wales (see, for example, Lucas and Le Souef 1909; Greer 1994; Tyler 1976, 1992) to being now known from only about 30 locations in this state (White and Pyke 1996). The decline in New South Wales appears to be continuing (Lunney *et al.* 1995; White and Pyke 1996).

The status of the Green and Golden Bell Frog outside of New South Wales is uncertain. It is not known whether populations of the species in Victoria have changed but the species is believed to be still present throughout its known range in Victoria and there are no known sites in that state where it has apparently disappeared (Gillespie 1996, pers. comm.). The species has been introduced into New Zealand, New Caledonia and the New Hebrides where it is stated to be locally abundant (Tyler 1976; Bell 1982).

In order to adequately conserve and manage the Green and Golden Bell Frog it is necessary to know and understand its habitat requirements. Only then can threatening processes be potentially controlled and recovery plans be initiated. If the habitat requirements are well enough defined, it may also be possible to protect the species through protection of areas where it is likely (but not necessarily known) to occur.

Judging from the published literature on the Green and Golden Bell Frog, this species occurs in a very wide range of conditions. It has been reported to inhabit virtually every conceivable kind of freshwater course and water body including swamps, wetlands and marshes (Fletcher 1889; Lucas and Le Souef 1909; Hoser 1989; Cogger 1992; Greer 1994; Bell 1982; Moore 1961), rivers, streams and creeks (Cogger 1992; Greer 1994; Bell 1982; Courtice and Grigg 1975; Hoser 1989; Lucas and Le Souef 1909; Moore 1961), lakes and lagoons (Cogger 1992; Bell 1982; Moore 1961), ponds (Cogger 1992; Greer 1994; Bell 1982; Courtice and Grigg 1975; Moore 1961) and farm dams (Cogger 1992; Courtice and Grigg 1975). Such a broad definition of suitable habitat provides little guidance in terms of how to manage the species and its habitat.

It is clear, however, that not every water course or water body within the geographical range of the Green and Golden Bell Frog is suitable for the species. Some sites that were once suitable for the species are now apparently unsuitable. Though originally very widespread, it did not occur in every freshwater location. Hence it should be possible to better define the habitat requirements of this species.

The aim of this paper is to determine the habitat requirements of the Green and Golden Bell Frog from a survey of a reasonably large number of known locations of the species. These locations include almost all of those sites in New South Wales where it has been recorded since 1990 as well as some from which it apparently disappeared earlier.

The present paper will differentiate between breeding and non-breeding habitat for the Green and Golden Bell Frog and will give particular attention to the breeding habitat of the species. A population of the species cannot maintain itself without successful reproduction. On the other hand, given the apparently strong dispersal abilities of the species (White 1995;

White and Pyke, unpubl. obs.), sheltering or moving individuals may easily occur in locations that are unsuitable for breeding. Hence, while the nature of sites where the species is found should give some indication of its habitat requirements, these requirements may be clearest when attention is devoted to breeding requirements.

METHODS

Almost all known locations in New South Wales where the Green and Golden Bell Frog has been found are described in White and Pyke (1996). These include 43 locations where the species has been recorded since 1990 (and possibly recorded earlier) and another 112 locations where the species was found earlier but where it has not been recorded since 1990 (White and Pyke 1996).

The present paper considers 74 of these known locations for the Green and Golden Bell Frog. These are the locations that we have so far visited and for which the necessary information is available (see below). They are locations that we believe have remained essentially unchanged between the last record of the species there and our visit, and for which, in the case of past records, we have enough detail concerning where the records were made to be able to determine the appropriate habitat details. The dates of these visits are presented in Table 1. All visits prior to 1994 were made by AW.

For the locations included in this paper we recorded the following information:

(a) nature of water present (i.e., "permanent" = permanent with little fluctuation in level; "fluctuating" = permanent with widely fluctuating water level; "ephemeral"; combinations of these);

(b) rate of water flow (i.e., still = no flow for most of the year; slow = regular flow at less than 1 m per minute; rapid = regular flow at more than 1 m per minute);

(c) maximum depth of water body in cm;

(d) surface area of water in square metres;

(e) substrate of water bodies (i.e., AS = alluvial sand, mean grain size 0.2–1.0 mm; AC = alluvial clay, mean grain size less than 0.2 mm; Rss = Rock base, exposed sandstone; Rsh = Rock base, exposed shale; R = Rubble consisting of broken rock pieces, bricks, building debris or industrial debris, larger than 1 cm^3; C = cement or concrete lined);

(f) nature and extent of any obvious evidence of water pollution (e.g., presence of human garbage, water discolouration, visible signs of eutrophication);

(g) aquatic plant species present or nearby;

(h) adjacent and nearby vegetation types (in addition to any areas of grass) within 50 m of frog observation (sensu Specht 1970; LOS = low open shrubland; LOW = low open woodland; W = woodland; OG = open grassland; LW = low woodland; TOS = tall open shrubland or scrubland; OS = open scrub; OH = open heath; OW = open woodland; S = sedgeland; LS = low shrubland; G = grassland; CH = closed heath);

(i) extent to which site is shaded (i.e., none, partial, full);

(j) nature of water source (i.e., UR = urban runoff; IR = industrial runoff; PR = parkland runoff; GR = grazing runoff; NR = natural vegetation runoff);

(k) nature of available diurnal shelter sites (e.g., A = artificial — including road ballast, road culvert, industrial debris, building debris, garbage; V = vegetation or plant cover; R = natural exposed rocks; T = fallen timber or logs);

(l) other frog species detected or known to be present and whether or not any species showed evidence of breeding (i.e., presence of eggs or tadpoles);

(Note, however, that full surveys of the frog fauna present at each site have not been carried out).

(m) whether Mosquito Fish, Carp, Eels or other fish species that are known or likely to prey on frog eggs or tadpoles are present (determined with a fish trap baited with bread and/or visibly);

(n) level of disturbance to site (i.e., high = significant disturbance to both the water regime and the surrounding areas; e.g., most industrial and urban sites; medium = significant disturbance to surrounding areas but little disturbance of water regime, e.g., pasture, parkland; low = only localized disturbance to surrounding areas and little disturbance to the water regimes; none = no obvious disturbance to either the surrounding area or to the water body).

In addition, for locations where breeding by the Green and Golden Bell was recorded, we collected this same information for the actual water body in which breeding occurred as well as for other nearby water bodies.

Because successful breeding activity is essential to long-term persistence of the Green and Golden Bell Frog in an area, we considered whether or not breeding had been reported from a location as the dependent variable and

Table 1. Summary of visits to known locations for the Green and Golden Bell Frog (GGBF) and of observations made at these locations

No.	Name	Visit details	Level of disturbance	Water flow	Substrate	Max. water depth	Water level	Water source	Visible water pollution
1	Arncliffe	1981–1995	High	Still	AS	30 cm	Ephemeral	UR	Yes
2	Bombah Point	1990–1994	Low	Still	AS	50 cm	Ephemeral	NR	No
3	Brundee Swamp	1993–1994	Medium	Slow	AS	50 cm	Ephemeral	GR	No
4	Braidwood	1993	Medium	Still	AC	1–2 m	Permanent	GR	No
5	Bundanoon	1991	High	Still	AS	25 cm	Permanent	NR	No
6	Byron Bay	1994–1995	High	Still	AS	1–2 m	Permanent	GR	No
7	Camden	1991	High	Still	Rss	50 cm	Permanent	GR	No
8	Coppin's Crossing	1990, 1993	Medium	Slow	Rsh	0–1 m	Permanent	GR	No
9	Cooma	1991	Medium	Still	Rsh	50 cm	Permanent	GR	No
10	Coomonderry Swamp	1993–1995	Low	Still	AS	0–1 m	Permanent	GR/NR	No
11	Coomonderry Pasture	1993–1995	Medium	Still	AS	15 cm	Ephemeral	GR	No
12	Darkes Forest	1978–1995	Low	Still	Rss	0–1 m	Permanent	NR	No
13	Diggers Camp	1994	Low	Still	AS	0–50 cm	Fluctuating	NR	No
14	Eastlakes Creek	1968–1995	High	Slow	AS	50 cm	Permanent	UR	Yes
15	Eastlakes Golf Course	1968–1995	Medium	Still	AS	15 cm	Ephemeral	PR	No
16	East Hills	1991, 1993	High	Still	AS	1–2 m	Permanent	UR	No
17	Fitzroy Falls	1991	Low	Slow	Rss	50 cm	Permanent	GR	No
18	Georges Hall	1974, 1993	High	Still	AC	50 cm	Ephemeral	UR	Yes
19	Greenacre Brickpit	1993–1995	High	Still	AC	2–4 m	Permanent	UR	No
20	Greenacre Marshalling Yards	1994–1995	High	Still	AC	30 cm	Permanent	UR	No
21	Greenacre Cox's Creek	1993–1995	Medium	Slow	AC	50 cm	Fluctuating	UR	Yes
22	Greenacre Stormwater	1993–1995	High	Still	AC	15 cm	Ephemeral	GR	No
23	Greenwell Point	1992	Low	Still	AS	50 cm	Permanent	PR	No
24	Hammondville Dam	1993–1995	Medium	Still	AC	1–2 m	Permanent	GR	No
25	Hammondville Pasture	1993–1995	Medium	Still	AC	15 cm	Ephemeral	GR	No
26	Helensburg	1970, 1994	Medium	Still	AS	50 cm	Permanent	UR	Yes
27	Holsworthy	1993	High		Rss	1–2 m	Permanent	PR	Yes
28	Homebush Brickpit	1993–1995	High	Still	Rsh	30 cm	Ephemeral	UR	No
29	Homebush Manure Pond	1993–1995	Medium	Still	C	1 m	Ephemeral	IR/VR	Yes
30	Homebush Concrete Tanks	1993–1995	High	Still	C	1 m	Ephemeral	UR	Yes
31	Homebush Lake Domis	1993–1995	High	Still	R	30 cm	Ephemeral	UR	No
32	Homebush Hill Road	1993–1995	High	Still	R	10 cm	Ephemeral	UR	Yes
33	Homebush Newington	1993–1995	Medium	Still	AC	0–1 m	Ephemeral	UR	Yes
34	Kemblawarra	1994	Low	Still	AS	0.5–1 m	Permanent	PR	No
35	Kioloa	1990, 1992	Low	Still	AS	1 m	Permanent	PR	No
36	Kilalea Lagoon	1994–1995	Low	Still	AS	0–1 m	Permanent	GR	No
37	Kurnell — north	1975, 1990–1995	Medium	Still	AS	0–30 cm	Ephemeral	NR	Yes
38	Kurnell — south	1975, 1990–1995	Medium	Still	AS	0–30 cm	Ephemeral	NR	No
39	La Perouse	1969, 1990–1995	Medium	Still	Rss	30 cm	Ephemeral	NR	No
40	Long-neck Lagoon	1973, 1994	Low	Still	AS	0–50 cm	Permanent	NR	No
41	Macksville	1975, 1990–1995	Medium	Still	AS	0–30 cm	Ephemeral	PR	Yes
42	Maroubra	1965, 1990–1995	High	Still	AS	50 cm	Fluctuating	UR	Yes
43	Mascot	1974, 1993	High	Still	AS	0–1 m	Ephemeral	UR	Yes
44	Mount Druitt	1994	High	Still	R	0–50 cm	Ephemeral	UR	No
45	Moruya Heads	1975, 1993	Medium	Still	AS	0–50 cm	Fluctuating	GR	No
46	Murray's Beach	1993–1995	Low	Still	Rss	0–1 m	Fluctuating	NR	No
47	Nadgee	1985	Low	Still	AS	0–1 m	Fluctuating	NR	No
48	North Ryde	1993–1995	High	Still	AC	0–1 m	Permanent	PR	No
49	Ocean Shores	1994	Medium	Still	AS	0–1 m	Fluctuating	UR	Yes
50	Oberon	1994	High	Slow	Rss	0–50 cm	Fluctuating	GR	Yes
51	Ourimbah	1970–1995	Medium	Slow	AS	0–1 m	Fluctuating	PR	No
52	Picton	1975, 1994	High	Still	Rss	30 cm	Permanent	GR	No
53	Pitt Town	1974, 1994	Medium	Still	AS	0–50 cm	Fluctuating	GR	Yes

etailed descriptions of these locations, see White and Pyke 1995; locations are numbered and listed alphabetically).

Aquatic plant species	Nearby Grassy area	Other nearby veg. types	Shelter sites	Predatory fish	Other frog species	Breeding recorded by GGBF	Surf area sq m
Typha	Yes	LOS	A,V	None	*Lim. peronii, Crinia signifera*	Yes	25
Typha, Phragmites	No	LOW	A,V	None	*Crinia signifera*	No	45
Typha	Yes	W	V,T	None	*Lim. peronii, Crinia signifera*	No	250
Typha, Eleocharis	Yes	OG	A	*Gambusia*	*Lim. peronii, Crinia signifera*	No	500
Eleocharis, Nymphoides, Water Lilies	Yes	LW	A	Goldfish *Carassius auratus*	*Litoria peronii, Lim. peronii*	No	25
Eleocharis, Juncus	No	LOW	V,T	None	*Litoria olongburensis, Crinia tinnula* + many others	No	1 00
Typha, Juncus	Yes	LW	V,T	*Gambusia*	*Litoria peronii, Lim. peronii*	No	700
Typha	Yes	LOW	V,A	Carp *Cyprinus carpio, Gambusia*	*Lim. peronii, Crinia signifera*	No	150
Eleocharis	Yes	OG	V,R	None	*Litoria verreauxi, Crinia signifera*	No	80
Typha, Eleocharis	Yes	TOS	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	0.01
Typha, Eleocharis	Yes	TOS	V	None	*Lim. peronii, Crinia signifera*	Yes	1 0
Eleocharis	Yes	OS	V	*Gambusia*	*Litoria dentata, Lim. peronii*	No	400
Typha, Juncus	No	OH	V	None	*Lim. peronii, Litoria peronii*	No	25
Typha, Phragmites	Yes	OG	V	*Gambusia*, Carp	*Lim. peronii, Crinia signifera*	No	1 25
Typha, Phragmites	Yes	OG	V	None	*Lim. peronii, Crinia signifera*	Yes	4
Eleocharis	Yes	OG	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	250
Eleocharis, Nymphoides, Water Lilies	Yes	OW	V,T	*Gambusia*, Rainbow Trout *Salmo gairdneri*	*Lim. peronii, Crinia signifera*	No	600
Juncus	Yes	LOW	V,T	*Gambusia*	*Lim. peronii, Litoria peronii*	No	8 0
Typha	Yes	OG	V,A	*Gambusia*	*Crinia signifera*	No	7 5
None	Yes	OG	A	None	*Crinia signifera*	No	200
Typha	Yes	TOS	V	Empire Gudgeon *Hypseleotris compressa*, Firetail Gudgeon *H. galli*	*Lim. peronii, Crinia signifera*	No	200
Typha	Yes	TOS	V	None	*Lim. peronii, Crinia signifera*	Yes	0.5
Eleocharis, Typha	Yes	LOW	V	None	*Lim. peronii, Litoria peronii*	Yes	500
Eleocharis	Yes	LOW	V	*Gambusia*, Redfin *Perca fluviallis*	*Lim. peronii, Crinia signifera*	No	1 6
Eleocharis	Yes	LOW	V	None	*Lim. peronii, Crinia signifera*	Yes	5
Typha, Eleocharis	Yes	OH	V,T	None	*Lim. peronii, Litoria peronii, Crinia signifera*	No	500
Typha	Yes	OG	V,R	*Gambusia*, Redfin	*Lim. peronii, Crinia signifera*	No	800
Typha, Juncus	Yes	OG	V,R,A	None	*Lim. peronii, Crinia signifera*	Yes	200
Kikuyu	Yes	OG	V	None	*Lim. peronii*	Yes	800
None	Yes	OG	A	None	*Lim. peronii*	Yes	40
None	Yes	OG	R	None	*Lim. peronii, Crinia signifera, Lim. tasmaniensis*	Yes	600
Juncus, Grass (?? Sp)	Yes	OG	V,A	None	*Lim. peronii, Crinia signifera*	Yes	4
None	Yes	LOW	V	None	*Lim. peronii, Lim. tasmaniensis, Crinia signifera*	Yes	20
Typha	Yes	LOS	V	*Gambusia*	*Lim. peronii*	Yes	3 0
Typha, Eleocharis	Yes	OW	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	500
Typha, Cyperus	Yes	OG	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	3 7
Juncus, Typha	Yes	S	V	None	*Crinia signifera*	No	10
Typha	No	LS	V	*Gambusia*	*Crinia signifera*	Yes	80
Juncus	Yes	LOS	A	None	*Lim. peronii, Crinia signifera*	No	10
Typha, Eleocharis	Yes	G	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	900
Typha	Yes	LOW	V	None	*Lim. peronii*	No	1 2
Typha	Yes	Og	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	100
Typha	Yes	LOW	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	4 0
Typha	Yes	OG	V,A	None	*Lim. peronii, Crinia signifera*	No	80
Typha	Yes	S	V,R	*Gambusia*	*Lim. peronii, Crinia signifera*	No	900
Juncus	Yes	OH	V,R	Eels (*Anguilla* sp.)	*Lim. peronii, Uperoleia laevigata, Crinia signifera*	No	500
Typha, Isolepis	No	CH	V,R	None	*Lim. peronii*	No	1 0
Eichhornia	Yes	OG	V	Lungfish *Neoceratodus forsteri*	*Lim. peronii, Crinia signifera*	Yes	400
Typha	Yes	OW	V	None	*Lim. peronii, Crinia signifera*	No	50
Typha	Yes	LOW	V,R	*Gambusia*, Carp	*Lim. peronii*	No	100
Typha	Yes	OW	V	*Gambusia*	*Lim. peronii, Litoria peronii*	No	100
Eleocharis	Yes	OW	V	*Gambusia*, Redfin	*Lim. peronii, Litoria peronii*	No	800
Typha, Phragmites	Yes	S	V	*Gambusia*	*Lim. peronii, Litoria peronii*	No	2 5

Table 1 — continued

No.	Name	Visit details	Level of disturbance	Water flow	Substrate	Max. water depth	Water level	Water source	Visible water pollution
54	Port Kembla	1994	High	Still	AS	0–30 cm	Fluctuating	IR	No
55	Primbee	1994	Medium	Still	AS	0–1 m	Fluctuating	PR	Yes
56	Ravensworth	1994	High	Still	AC	50 cm	Ephemeral	GR	Yes
57	Raymond Terrace	1973, 1990–1995	High	Still	AS	0–50 cm	Fluctuating	UR	Yes
58	Richmond	1978, 1993	High	Still	AS	0–1 m	Fluctuating	GR	No
59	Rosebery	1993–1995	High	Still	AS	0–1 m	Fluctuating	UR	No
60	Ryan's Swamp	1993–1995	Low	Still	AS	0–1 m	Fluctuating	NR	No
61	Sans Souci	1988, 1990–1995	High	Still	AS	0–30 cm	Ephemeral	UR	Yes
62	Shellharbour	1993–1995	Medium	Still	AS	0–30 cm	Fluctuating	UR	Yes
63	Smith's Lake	1972–1995	Low	Still	AS	0–1 m	Fluctuating	NR	No
64	Shoalhaven Heads	1992	Low	Still	AS	0–50 cm	Fluctuating	GR	No
65	Telegraph Point	1991	Low	Still	AS	0–1 m	Fluctuating	GR	No
66	University of Canberra	1990, 1993	Low	Still	Rsh	0–50 cm	Fluctuating	PR	No
67	Woolooware	1994	Low	Still	AS	0–30 cm	Ephemeral	PR	Yes
68	Wanda	1994–1995	Medium	Still	AS	1–2 m	Permanent	NR	No
69	Yuragir Blue Lagoon	1994	Low	Still	AS	0–2 m	Fluctuating	NR	No
70	Yuragir Station Creek	1994	Low	Still	AS	0–50 cm	Fluctuating	NR	No
71	Uriarra	1990, 1995	Low	Slow	Rsh	0–1 m	Permanent	GR	No
72	Warrell Creek	1975, 1994	Low	Slow	AS	0–1 m	Fluctuating	GR	No
73	Woragi Swamp	1993	Medium	Still	AS	0–50 cm	Ephemeral	GR	Yes
74	Wyong	1993	Medium	Still	AS	0–50 cm	Fluctuating	PR/NR	Yes

the other observations made at each location as independent variables (see Table 1). In cases, where there were small sample sizes for some variable categories, these categories were combined with others (see below).

We used stepwise loglinear analysis to determine which variables showed differences between breeding and non-breeding (i.e., breeding not known) locations (see Sokal and Rohlf 1981). Variables were added so long as their addition resulted in a significant increase in the likelihood ratio χ^2. At each step the variable which resulted in the greatest increase in the χ^2 value was added. For the resulting variables we present the results separately for breeding and non-breeding locations. For the other variables we present the results for all locations combined.

RESULTS

Locations where breeding of the Green and Golden Bell Frog had been successful (i.e., resulted in eggs or tadpoles) differed significantly from other locations where the species has been found with respect to the degree to which the water body is permanent vs. ephemeral (Log-linear analysis: $\chi^2_1 = 10.71$, $P = 0.005$). Breeding has occurred in a significantly higher proportion of sites with ephemeral ponds rather than of sites with fluctuating or permanent ponds (Table 2) and there is no significant difference between fluctuating and permanent ponds in terms of the proportion of ponds known to support successful breeding (Log-linear analysis: $\chi^2_1 = 0.17$, $P = 0.68$). To maximize the numbers of ponds per cell in subsequent three or higher-way cross-tabulation for further analysis, the categories fluctuating and permanent were therefore combined (see below).

Table 2. Effect of water level on breeding by the GGBF.

Nature of water level	Breeding known	Breeding not known
Permanent	4	21
Fluctuating	3	22
Ephemeral	12	12

Breeding and non-breeding ponds also differed significantly in terms of whether or not predatory fish were present (Log-linear analysis: 1st variable entered — ephemeral vs. fluctuating or permanent — $\chi^2_1 = 10.54$, $P = 0.001$; 2nd variable entered — whether or not predatory fish present — χ^2_3 for additional variable = 19.46, $P = 0.001$). Breeding has occurred more frequently in ponds that do not have predatory fish present rather than in ones that do (Table 3).

Table 3. Effect of presence of predatory fish on breeding by the GGBF.

Predatory fish	Breeding known	Breeding not known
Present	5	35
Absent	14	20

Shade	Aquatic plant species	Nearby Grassy area	Other nearby veg. types	Shelter sites	Predatory fish	Other frog species	Breeding recorded by GGBF	Surface area sq m
None	*Typha*	Yes	OG	V	None	*Lim. peronii*	No	400
None	*Typha*	Yes	OG	V	*Gambusia*	*Lim. peronii, Crinia signifera*	Yes	2 500
None	*Typha*	Yes	OG	V	None	*Lim. peronii, Crinia signifera*	No	25
Partial	*Typha, Juncus*	Yes	OW	V	*Gambusia*	*Lim. peronii*	No	3 500
None	*Typha*	Yes	OG	V	*Gambusia*	*Lim. peronii*	No	6 000
None	None	Yes	OG	R	None	*Crinia signifera*	Yes	800
None	*Eleocharis*	Yes	OW	V,T	None	*Litoria peronii, Lit. jervisiensis Lim. peronii, Crinia signifera, Uperoleia laevigata*	No	2500
Partial	*Juncus*	Yes	W	V	*Gambusia*	*Crinia signifera*	No	700
None	*Typha*	Yes	LS	A	*Gambusia*	*Crinia signifera*	No	10
None	*Eleocharis, Juncus*	No	CH	V	None	*Lim. peronii, Crinia signifera*	No	1 500
None	*Typha*	Yes	CG	V	*Gambusia*	*Lim. peronii, Crinia signifera*	Yes	400
None	*Typha*	Yes	TOS	V	*Gambusia*	*Crinia signifera*	No	600
Partial	*Typha*	Yes	LOW	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	40
None	*Typha*	No	LOS	V	None	*Crinia signifera*	No	75
None	*Typha, Eleocharis*	Yes	LOS	V	*Gambusia*	*Lim. peronii, Crinia signifera*	Yes	3 500
Partial	*Typha*	Yes	CH	V	None	*Lim. peronii*	No	40 000
Partial	*Typha*	Yes	LOS	V	None	*Lim. peronii*	No	20
Partial	*Typha*	Yes	LW	V	*Gambusia*, Carp	*Crinia signifera*	No	1 000
None	*Typha*	Yes	LS	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	4 000
None	*Cyperus, Eleocharis*	Yes	W	V,A	*Gambusia*	*Crinia signifera*	No	1 200
None	*Typha, Eleocharis*	Yes	TOS	V	*Gambusia*	*Lim. peronii, Crinia signifera*	No	10 000

The most prevalent predatory fish was the Mosquito Fish *Gambusia holbrooki* (see also Morgan 1996). It was one of, if not the only, predatory fish present at 36 sites. Other predatory fish were present without *Gambusia* at only four sites.

The total sample size of ponds is not large enough to permit further determination of significant differences between breeding and non-breeding ponds. When such analysis is attempted, too many of the classification cells contain fewer than five observations. Breeding and non-breeding ponds were therefore combined in further examining properties of ponds used by the Green and Golden Bell Frog.

Tabulating the information for each variable in Table 1 reveals that sites where the Green and Golden Bell Frog has been found have the following properties:

(a) most have vegetation providing potential sites for diurnal shelter; other kinds of potential shelter sites occur in a minority of ponds (Table 4);

Table 4. Potential diurnal shelter sites available.

Shelter type	Present	Absent
Artificial	14	60
Rock	9	65
Timber	7	67
Vegetation	66	8

(b) most have the frogs *Crinia signifera* or *Limnodynastes peronii* present (Table 5);

Table 5. Known presence/absence of *Crinia signifera* and *Limnodynastes peronii*.

Frog species	Known to be present	Not known to be present
Crinia signifera	53	21
Limnodynastes peronii	60	14

(c) most have been moderately or highly disturbed, and none are apparently undisturbed (Table 6);

Table 6. Level of disturbance to site.

Level of disturbance	Number of sites
High	26
Medium	26
Low	22
None	0

(d) almost all sites have some aquatic plant species present (Table 1); in most cases *Typha* sp. is present (Table 7);

Table 7. Aquatic plant species present.

Plant species	Present	Absent
Typha sp.	49	25
Eleocharis sp.	19	55
Juncus sp.	11	63

(e) most have still water, a few have slow moving water, and none have rapid flowing water (Table 8);

Table 8. Rate of water flow.

Rate of water flow	Number of sites
Still	64
Slow	10
Rapid	0

(f) the water source for most sites is either urban/industrial runoff or runoff from grazing or park land; for a minority of sites the source is runoff from natural vegetation (Table 9);

Table 9. Nature of water source.

Water source	Number of sites
Industrial/Urban	24
Grazing	23
Parkland/Natural vegetation	27

(g) the substrate is mostly sand or rock but is clay in some cases (Table 10);

Table 10. Type of substrate.

Substrate	Number of sites
Alluvial clay	11
Alluvial sand	45
Rock/concrete	18

(h) most sites have ponds which are shallow with maximum water depth less than 50 cm (Table 11);

Table 11. Maximum depth of water.

Depth	Number of sites
0–50 cm	43
50–100 cm	22
100–200 cm	9

(i) the ponds have surface areas that range from only about 0.01 m^2 up to about 40 000 m^2 with a median surface area of 500 m^2; most are no more than 1 000 m^2 in surface area (Table 12);

Table 12. Surface area of water body.

Surface area	Number of sites
0–100 m^2	23
101–1 000 m^2	31
>1 000 m^2	20

(j) nearby vegetation is generally low, ranging from grassland and heath to shrubland and woodland; no sites have nearby forest (Table 13);

Table 13. Nearby vegetation.

Nearby vegetation	Number of sites
Grassland	22
Heathland	6
Shrubland	20
Woodland	26

(k) most are unshaded and none are completely shaded (Table 14);

Table 14. Extent of shade over water body.

Shade	Number of sites
None	49
Partial	25
Complete	0

(l) most have an area of grass nearby (Table 15);

Table 15. Presence/absence of other factors.

Factor	Present	Absent
Nearby grassy area	67	7
Visible pollution	25	49

(m) most have no visible signs of water pollution (Table 15).

DISCUSSION

The above analysis indicates that for a location to be likely to support a population of the Green and Golden Bell Frog in New South Wales it should have the following related attributes:

- There should be a grassy area reasonably near to any water bodies, and other nearby vegetation should be woodland or lower in maximum height;
- The substrate should be sand or rock;
- The water bodies should be still, shallow, ephemeral and unpolluted. Such water bodies are most likely to occur in areas which experience disturbance (either natural or unnatural) and where surface water runoff from local unpolluted areas collects to form temporary ponds;
- The water bodies should be unshaded and free of *Gambusia* and other predatory fish;
- There should be aquatic plants present, preferably *Typha* sp.;
- There should be a range of possible diurnal shelter sites available, including vegetation and rocks.

A location with these attributes should cater for all the known biological requirements of the Green and Golden Bell Frog. Feeding may occur in the grassy area (e.g., Lucas and Le Souef 1909) or amid the aquatic vegetation (e.g., Courtice and Grigg 1975). Basking may occur on the vegetation in and near the pond (e.g., Bell 1982; Fletcher 1889; Hoser 1989; Pastorelli 1990; Greer 1994). The frogs may shelter during the day among the vegetation or under rocks (e.g., Fletcher 1889; Bell 1982; Pastorelli 1990; Greer 1994). They may overwinter among piles of rocks (e.g., Bell 1982). The pond area may provide suitable conditions for spawning, hatching and tadpole growth and development (e.g., Fletcher 1889; Courtice and Grigg 1975; Bell 1982).

The above analysis also indicates that for a location to be likely to support a breeding population of the Green and Golden Bell Frog in New South Wales it is highly desirable that it consist of an ephemeral pond that is free of predatory fish. It is likely, furthermore, that these attributes are, in fact, mandatory for successful breeding. While a few instances have been found where tadpoles of the Green and Golden Bell Frog and *Gambusia* have been observed in the same water body (see Table 1), it is likely, given the extent to which *Gambusia* prey on tadpoles of this species (Morgan 1996; White, unpubl. obs.), that survival of these tadpoles was ultimately very low. It is also possible that water bodies which initially contain eggs and tadpoles without *Gambusia* may subsequently become joined with water bodies that contain *Gambusia* as overall water levels rise.

These habitat requirements in New South Wales may differ from those which occur in Victoria. Almost all the known locations of the Green and Golden Bell Frog in New South Wales have been disturbed by human activities such as sand mining or quarrying, and breeding is apparently restricted to ephemeral ponds. However, in Victoria, many known locations for the species have been subject to relatively little human disturbance and breeding in this State has been observed in relatively permanent, non-fluctuating ponds as well as in ephemeral and fluctuating ponds (Gillespie, pers. comm.). Hence, either the species has quite different habitat requirements in New South Wales and Victoria, or the underlying and fundamental requirements may be associated in New South Wales with ephemeral and/or fluctuating ponds, and with all kinds of ponds, including permanent ones, in Victoria.

The observation that almost all of the known locations in New South Wales have been disturbed by human activities, and indeed, that some are completely artificial, suggests that it should be possible to develop additional artificial habitat for the species (e.g., Greer 1994; Pyke 1995). This would presumably be difficult or impossible for species which require attributes of natural or undisturbed habitats.

While artificial habitat specifically designed for frogs has been developed on a number of occasions in the northern hemisphere (e.g., Langton 1989), there have not apparently been any similar attempts in the southern hemisphere. Consequently, the development of artificial breeding habitat for the Green and Golden Bell Frog at Homebush Bay in New South Wales is apparently the first such development in the southern hemisphere (Greer 1994; Pyke 1995).

Based primarily on the above analysis of habitat requirements for the Green and Golden Bell Frog and, to a small extent, on other available information on the biology of the species, we have formulated the following guidelines for the development and/or management of ponds and associated habitat suitable for breeding by this species (see also Pyke 1995):

(i) Whenever possible the underlying substrate of a pond should be sand or crushed and/or broken rock with clay used when this is not possible;

(ii) Ponds should have one end relatively deep (i.e., about 0.5 to 1 m deep at deepest point about 1–2 m from the deep end of the pond) and the other end shallow (i.e., about 10–15 cm deep at a distance of 1 m away from the edge) (this design should result in the water level fluctuating in accordance with rainfall patterns but one part of the pond tending to remain relatively wet when the other end dries up);

(iii) Water should enter a pond at its deeper end;

(iv) Ponds may vary in size, ranging from about 3–5 m long and 1–2 m wide to about 5–10 m long and 3–5 m wide (pond size should be adjusted to suit local conditions and to maximize the total number of ponds);

(v) Piles of rocks each with a cross-sectional length of about 30–50 cm should be deposited at the deeper end of the pond, extending for 2–3 m along the edge of the pond, for 1–2 m below maximum water level and for 3–5 m above maximum water level, and reaching a height of about 50 cm above the maximum water level (this should provide diurnal and longer-term shelter sites for the frogs);

(vi) Clumps of aquatic plants (preferred plant genera include *Typha, Eleocharis, Juncus* and others such as *Phragmites*) should be established at the deeper end of the pond. In some cases, *Typha* may be viewed as a last resort because of likely difficulties in managing it; e.g., Pyke (1995) (these clumps should provide sites for basking, diurnal shelter and possibly feeding by the frogs);

(vii) Areas adjacent to and between the ponds should be sown with native grass and maintained as a grassland (this should provide feeding habitat for the frogs);

(viii) Trees should **NOT** be planted so as to shade any of the pond area or to detract from the grassland character of the area near the ponds (this should protect the site from shading);

(ix) There should be a provision to drain each pond should this be necessary either to remove *Gambusia* or other undesirable aquatic species or to simulate natural fluctuations in water level;

(x) The water inflow into these ponds should be kept as clean and free of added nutrients as possible. In particular, fertilizer, herbicide, pesticide, and other chemical treatment should not be used within the catchments of these frog breeding ponds.

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